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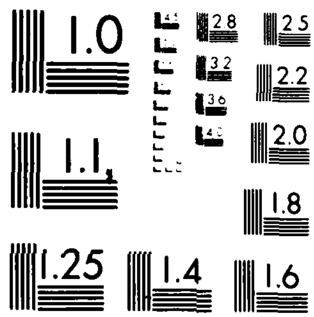

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LONG TERM EVALUATION OF THE EFFECTS OF SHALE OIL PRODUCED JP-4 ON AIRCRAFT CONSTRUCTION MATERIALS

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APRIL 1983

Interim Technical Report March 1980 - April 1982

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Shale Oil Produced JP-4	Elastomeric Materials
Petroleum Produced JP-4	Structural Adhesives
Petroleum Produced JP-8	Fuel Tank Coatings

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Various fuel system materials including elastomers, structural adhesives, and tank coatings were subjected to accelerated agings in both petroleum produced and shale oil produced JP-4 fuels. Comparisons were made of the test results in the different fuels.

There was no significant difference in the test results for most materials. There was, however, significantly more deterioration of buna N and polyurethane elastomers in shale oil JP-4 than in petroleum derived JP-4. Repeat tests in

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a second supply of shale oil JP-4 did not result in the buna N and polyurethane deterioration. The results indicate that the first batch of shale oil JP-4 was contaminated although the contaminant could not be identified. Subsequent testing will be done with future batches of shale oil JP-4 to insure there is not a problem.

PREFACE

This interim technical report was submitted by the University of Dayton Research Institute, Dayton, Ohio, under Contract F33615-82-C-5039, "Quick Reaction Evaluation of Materials." The work was administered under the direction of the Air Force Wright Aeronautical Laboratories, Materials Laboratory, Materials Support Division, Wright-Patterson Air Force Base, Ohio.

This effort was conducted during the period of March 1980 to April 1982. The authors wish to recognize Messrs. J. R. Conner and A. L. Logue of the University of Dayton, who were responsible for much of the materials testing, and to Mrs. Jeanne Drake and Miss Julia Zimmermann, secretaries, who organized and typed this report.

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I. INTRODUCTION

JP-4 produced from shale oil is to be used as fuel for U.S. aircraft. Although the fuel conforms to the requirements of MIL-J-5624, there was concern that undetermined contaminants could adversely affect some aircraft construction materials. A program to evaluate the effect of fuel exposure on elastomeric materials, structural adhesives, and fuel tank coatings was conducted using three test fluids, MIL-J-5624, Grade JP-4 (Shale Oil Source); MIL-J-5624, Grade JP-4 (Petroleum Source); and MIL-T-83133, Grade JP-8 (Petroleum Source).

II. PROCEDURES AND TEST RESULTS

This section describes the test fluids, identifies the materials under test, and summarizes the test results.

Test Fluids

Three aircraft fuels were utilized as test fluids for progressive conditioning of the elastomers, adhesives, and coatings at specified intervals up to six months. Subsequent agings of selected materials were conducted for 360 days. The test fluids included:

MIL-J-5624, Grade JP-4 (Shale Oil Source)
MIL-J-5624, Grade JP-4 (Petroleum Source)
MIL-T-83133, Grade JP-8 (Petroleum Source)

In order to provide a worst-case fuel environment for the construction materials, portions of both shale oil JP-4 and petroleum JP-4 were also altered to contain 25 percent aromatics, 0.4 percent sulfur, and 0.005 percent Mercaptan by weight. Materials agings were simultaneously conducted using the altered fuels.

Elastomeric O-Ring Materials

Four O-ring materials were specified as representative seal materials. They included two buna-N elastomers, one fluorosilicone, and one fluoroelastomer. The materials, each conforming to an appropriate specification, were obtained from two manufacturers. They included:

AMS-7271, Buna-N, Parker N-506
MIL-P-5315, Buna-N, Precision 7866
MIL-P-25988, Fluorosilicone, Precision 11647
MIL-R-83248, Fluoroelastomer, Parker V747

O-ring evaluations included the determination of ultimate tensile strength, percent elongation, percent volume swell, and

hardness as a function of aging in fuel. Tests were conducted after conditioning at the following intervals:

A. None (Original properties)

B. 7 days at 140°F in Petroleum JP-4

C. 7 days at 140°F in Shale Oil JP-4

D. 6 months at 140°F in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

H. After aging 14 days at 140°F in Petroleum JP-4 followed by 7 days at 140°F in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F in Petroleum JP-8 followed by 7 days at 140°F in Shale Oil JP-4 (also, measure volume change when removed from JP-8)

J. After aging 14 days at 77°F in Petroleum JP-4 followed by 7 days at 77°F in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

K. After aging 14 days at 77°F in Petroleum JP-8 followed by 7 days at 77°F in Shale Oil JP-4 (also, measure volume change when removed from JP-8)

MIL-R-83248, Type I, Class 1, Grade 75-Fluoroelastomer Only

L. After aging 7 days at 300°F in Petroleum JP-4

M. After aging 7 days at 300°F in Shale Oil JP-4.

These results are summarized in Tables 1 and 2. As indicated in Table 1, the tensile strengths of both buna-N materials were substantially affected after six months in shale oil produced JP-4. Volume swell properties for all four elastomers were lower after aging in shale oil JP-4 than in either petroleum JP-4 or JP-8.

Because of the marked change in properties of buna-N after exposure to shale oil JP-4, an analysis of the fuel was initiated. The shale oil JP-4 used in these tests was produced for the Air Force by Hydrocarbon Research Incorporated (HRI) under subcontract to Suntech in January 1980. The details of the production conditions for this shale oil JP-4 are documented in AFWAL-TR-81-2087. The shale oil JP-4 used in the initial compatibility tests had been obtained from fuel left over after completion of engine tests at General Electric, Evendale. Extensive discussions with Suntech revealed that the initial production of test fuel (which was subsequently delivered to the General Electric Company and ultimately was used in the initial compatibility testing) had failed the copper strip corrosion test required by MIL-T-5624. The test fuel producer believes that hydrogen sulfide, produced in the activation of the hydrocracking catalyst, was carried with the fuel through the processing plant stripper which was intended to remove the hydrogen sulfide. The producer initially used benzotriazole to negate the corrosive effects of the sulfur on the copper strip (this is apparently a common refinery practice). It is believed that either hydrogen sulfide or free sulfur in the fuel caused the decrease in tensile strength of the buna-N material as well as the initial failure of the copper strip corrosion test. Sulfur compounds are known to cause these problems. Although laboratory analyses failed to verify the presence of either hydrogren sulfide or free sulfur in this fuel, it did have a noticeable yellowish appearance as opposed to the clear,

colorless appearance of the petroleum produced fuels. It was also suspected that the benzotriazole might have affected the buna-N properties. The producer reported that subsequent to the production of the fuel for General Electric, Evendale, adjustments in the operating conditions of the stripper eliminated the copper corrosion problems and the need for the addition of the benzotriazole. Fuel produced subsequent to the copper corrosion problem was supplied to Pratt & Whitney. A sample of the new batch of shale oil JP-4 was obtained from Pratt & Whitney for compatibility testing. The fuel from Pratt & Whitney had the same clear appearance as the petroleum produced fuels. Benzotriazole was added to petroleum JP-4 to determine any effect of the additive on buna-N. Precision 7866 buna-N O-rings were tested using four fuels:

Shale oil produced JP-4 from GE Evendale

Shale oil produced JP-4 from Pratt & Whitney

Petroleum produced JP-4

Petroleum produced JP-4 with 5 ppm of benzotriazole

Agings selected for testing were:

A. None (original properties)

B. 30, 60, 90, 120, 150, 180, 270, and 360 days at 140°F (60°C) in each of the four fuels.

Fuel changes were made every 30 days for longer agings.

The results of the retest of buna-N material are summarized in Tables 3 through 6. Table 3 indicates that the O-rings aged in Evendale fuel had a 70 percent loss in tensile strength after aging for 120 days. The O-rings aged in petroleum JP-4 with

TABLE 1

ELASTOMERIC O-RING MATERIALS

Conditioning	AMS-7271 Buna-N Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell	MIL-P-5315 Buna-N Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell
Controls	2110	(14.6)	500			1410	(9.7)	380	62	
7 Days at 140°F (60°C) in Pet. JP-4	1560	(10.8)	290	---	20	1130	(7.8)	200	54	11
7 Days at 140°F (60°C) in Shale JP-4	1760	(12.1)	340	---	17	1260	(8.7)	220	52	9
7 Days at 140°F (60°C) in Pet. JP-4[1]	1430	(9.8)	440	---	28	840	(5.8)	290	48	19
7 Days at 140°F (60°C) in Shale JP-4[1]	1490	(10.3)	340	---	27	1110	(7.7)	220	52	20
6 Months at 140°F (60°C) in Pet. JP-4	1550	(10.7)	280	---	16	870	(6.0)	150	65	5
6 Months at 140°F (60°C) in Shale JP-4	630	(4.3)	180	---	13	200	(1.4)	10	75	0

[1]25% Aromatic content; 0.4% Sulfur; 0.0005% Mercaptan

TABLE 1 (cont.)

ELASTOMERIC O-RING MATERIALS

Conditioning	AMS 7271 Buna-N						MIL-P-5315 Buna-N					
	Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell		Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell	
14 Days at 140°F (60°C) in Pet. JP-4 +					18					53	8	
7 Days at 140°F (60°C) in Shale JP-4	1830	(12.6)	340	---	16		1190	(8.2)	230	56	6	
14 Days at 77°F (25°C) in Pet. JP-4 +					19					52	8	
7 Days at 77°F (25°C) in Shale JP-4	1790	(12.3)	350	---	17		1280	(8.8)	230	58	5	
14 Days at 140°F (60°C) in JP-8 +					18					58	8	
7 Days at 140°F (60°C) in Shale JP-4	1730	(11.9)	320	---	16		1150	(7.9)	190	58	6	
14 Days at 77°F (25°C) in JP-8 +					16					56	8	
7 Days at 77°F (25°C) in Shale JP-4	1640	(11.3)	340	---	16		1290	(8.9)	230	56	7	

TABLE 2

ELASTOMERIC O-RING MATERIALS

Conditioning	MIL-R-25988 Fluorosilicone Type I, Class 1, Grade 70					MIL-R-83248 Fluoroelastomer Type I, Class 1, Grade 75				
	Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell	Tensile Strength psi	(MPa)	% Elong.	Hardness	% Vol. Swell
Controls	650	(4.5)	270	57		1710	(11.8)	280	77	
7 Days at 140°F (60°C) in Pet. JP-4	460	(3.2)	140	51	16	1540	(10.6)	190	75	6
7 Days at 140°F (60°C) in Shale JP-4	470	(3.2)	140	50	11	1720	(11.9)	200	74	2
7 Days at 140°F (60°C) in Pet. JP-4[1]	420	(2.9)	190	48	16	1370	(9.4)	280	69	7
7 Days at 140°F (60°C) in Shale JP-4[1]	480	(3.3)	145	54	13	1470	(10.1)	180	76	5
7 Days at 300°F (149°C) in Pet. JP-4	430	(3.0)	160	48	14	1540	(10.6)	170	77	9
7 Days at 300°F (149°C) in Shale JP-4	400	(2.8)	160	53	13	1690	(11.6)	180	78	7
6 Months at 140°F (60°C) in Pet. JP-4	450	(3.1)	180	56	12	1580	(10.9)	190	78	4
6 Months at 140°F (60°C) in Shale JP-4	480	(3.3)	140	58	7.5	1590	(11.0)	190	75	3

[1]25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 2 (cont.)

ELASTOMERIC O-RING MATERIALS

Conditioning	MIL-R-25988 Fluorosilicone Type I, Class 1, Grade 70					MIL-R-83248 Fluoroelastomer Type I, Class 1, Grade 75				
	Tensile Strength psi	Tensile Strength (MPa)	% Elong.	Hardness	% Vol. Swell	Tensile Strength psi	Tensile Strength (MPa)	% Elong.	Hardness	% Vol. Swell
14 Days at 140°F (60°C) in Pet. JP-4 +				50	13				75	4
7 Days at 140°F (60°C) in Shale JP-4	520	(3.6)	150	53	11	1540	(10.6)	190	78	4
14 Days at 77°F (25°C) in Pet. JP-4 +				48	11				77	2
7 Days at 77°F (25°C) in Shale JP-4	550	(3.8)	170	57	10	1730	(11.9)	200	76	2
14 Days at 140°F (60°C) in JP-8 +				53	7				79	3
7 Days at 140°F (60°C) in Shale JP-4	580	(4.0)	170	55	8	1660	(11.4)	200	78	5
14 Days at 77°F (25°C) in JP-8 +				55	6				78	0.6
7 Days at 77°F (25°C) in Shale JP-4	510	(3.5)	160	55	10	1600	(11.0)	200	78	0.8

TABLE 3

ELASTOMERIC O-RING MATERIAL

MIL-P-5315 Buna-N

Tensile Strength

Test Fluids	Days Aging at 140°F (60°C)																	
	Original		30		60		90		120		150		180		270		360	
	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)	psi	(MPa)
Shale oil produced JP-4 from GE Evendale	1380	(9.5)	1350	(9.3)	1350	(9.3)	975	(6.7)	410	(2.8)	540	(3.7)	460	(3.2)	340	(2.4)	310	(2.1)
Shale oil produced JP-4 from Pratt & Whitney	1380	(9.5)	1290	(8.9)	1290	(8.9)	1190	(8.2)	1170	(8.1)	1260	(8.7)	1220	(8.4)	1210	(8.4)	1170	(8.1)
Petroleum produced JP-4	1380	(9.5)	1270	(8.8)	1310	(9.0)	1160	(8.0)	1120	(7.7)	1250	(8.6)	1110	(7.7)	1060	(7.3)	990	(6.8)
Petroleum produced JP-4 with 5ppm benzotriazole	1380	(9.5)	1120	(7.7)	1260	(8.7)	1210	(8.3)	1120	(7.7)	1100	(7.6)	1170	(8.1)	920	(6.3)	660	(4.6)

TABLE 4

ELASTOMERIC O-RING MATERIAL

MIL-P-5315 Buna-N

	Percent Elongation								
	Days Aging at 140°F (60°C)								
Test Fluid	Original	30	60	90	120	150	180	270	360
Shale oil produced JP-4 from GE Evendale	380	225	220	150	90	110	80	45	30
Shale oil produced JP-4 from Pratt & Whitney	380	210	205	180	180	210	180	175	180
Petroleum Produced JP-4	380	220	205	180	190	220	180	180	150
Petroleum produced JP-4 with 5 ppm benzotriazole	380	200	210	195	180	180	190	160	130

TABLE 5

ELASTOMERIC O-RING MATERIAL

MIL-P-5315 Buna-N

	Hardness								
	Days Aging at 140°F (60°C)								
Test Fluids	Original	30	60	90	120	150	180	270	360
Shale oil produced JP-4 from GE Evendale	70	60	63	67	66	67	69	75	77
Shale oil produced JP-4 from Pratt & Whitney	70	60	65	67	69	69	67	71	69
Petroleum produced JP-4	70	60	62	65	65	67	65	68	69
Petroleum produced JP-4 with 5 ppm benzotriazole	70	61	63	63	65	63	65	65	67

TABLE 6

ELASTOMERIC O-RING MATERIAL

MIL-P-5315 Buna-N

Percent Volume Swell

	Days at 140°F (60°C)								
Test Fluids	Original	30	60	90	120	150	180	270	360
Shale oil produced JP-4 from GE Evendale		8.1	6.6	6.2	5.4	4.9	5.4	4.5	5.4
Shale oil produced JP-4 from Pratt & Whitney		6.9	5.2	5.4	4.0	4.3	4.7	3.8	5.3
Petroleum produced JP-4		9.2	7.7	7.8	7.0	6.9	6.6	6.6	6.3
Petroleum produced JP-4 with 5 ppm benzotriazole		7.6	8.1	7.8	6.2	7.9	6.1	6.4	6.3

benzotriazole showed some decrease in tensile strength after 270 days, and a loss of 50 percent after 360 days. No appreciable loss in tensile strength was noted for the buna-N after 360 days in either petroleum JP-4 or shale oil JP-4 from Pratt & Whitney. These data tend to substantiate the relationship between the hydrogen sulfide caused copper strip corrosion problem and the materials compatibility problem.

Another test to determine the effect of the Evendale fuel on buna-N was conducted during the above evaluation of fuels. Two sets of Precision 7866 O-rings were conditioned for 20 weeks at 140°F (60°C). Weekly fuel changes were made on one set of O-rings. Fuel was not changed for the second set during the 20 week aging. As shown in Table 7, buna-N lost approximately 70 percent of its original tensile strength after 20 weeks with weekly fuel changes. No appreciable loss of tensile strength was noted for these rings aged in fuel without weekly changes.

Fuel Tank Sealants - Curing Type

Five two-part, curing type sealants were included in the materials evaluation. One fluorosilicone sealant, DQ94-002, was also evaluated. The materials included:

MIL-S-8802, Type I PR-1422 B-2 Dichromate cured
MIL-S-8802, Type II PS 890 B-2 Manganese dioxide cure
MIL-S-83430 PR 1750 B-2 Manganese dioxide cure
MIL-S-83430 PS 899 B-2 Manganese dioxide cure
MIL-S-7502 PR-1221 B-2 Lead dioxide cure
Fluorosilicone DQ94-002 with 1200 primer.

Peel strength properties were determined on MIL-C-27725 polyurethane coated aluminum panels for all sealants except the MIL-S-7502 material, which was applied to QQ-A-250/13 clad aluminum. Volume change determinations were also made for each material after the following agings:

A. None (Original properties)
B. 7 days at 140°F (60°C) in Petroleum JP-4
C. 7 days at 140°F (60°C) in Shale Oil JP-4

TABLE 7

ELASTOMERIC O-RING MATERIAL

MIL-P-5315 Buna-N

	Fuel Changes Weekly		No Fuel Change	
	Tensile Strength psi (MPa)	Percent Elongation	Tensile Strength psi (MPa)	Percent Elongation
4 weeks at 140°F (60°C) in shale oil JP-4 (Evendale)	1140(7.9)	200	1290(8.9)	200
8 weeks at 140°F (60°C) in shale oil JP-4 (Evendale)	1150(7.9)	200	1320(9.1)	200
12 weeks at 140°F (60°C) in shale oil JP-4 (Evendale)	870(6.0)	160	1310(9.0)	190
16 weeks at 140°F (60°C) in shale oil JP-4 (Evendale)	580(4.0)	100	1340(9.2)	190
20 weeks at 140°F (60°C) in shale oil JP-4 (Evendale)	430(3.0)	70	1320(9.1)	150

D. 6 months at 140°F(60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F(60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F(60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F(60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

H. After aging 14 days at 140°F(60°C) in Petroleum JP-4 followed by 7 days at 140°F(60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F(60°C) in Petroleum JP-8 followed by 7 days at 140°F(60°C) in Shale Oil JP-4 (Also, measure volume change when removed from JP-8)

J. After aging 14 days at 77°F(25°C) in Petroleum JP-4 followed by 7 days at 77°F(25°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

K. After aging 14 days at 77°F (25°C) in Petroleum JP-8 followed by 7 days at 77°F (25°C) in Shale Oil JP-4 (also, measure volume change when removed from JP-8).

Peel strength and volume change results are presented in Tables 8 through 10. All peel strength failure modes were 100 percent cohesive. The effect of the different fuels on peel strengths of any of the sealant materials was not measurable. The effect of long-term aging in either petroleum JP-4 or shale oil JP-4 was significant for the MIL-S-8802, Type II sealant and for one MIL-S-83430 sealant, both of which were manganese dioxide cure systems.

Volume changes for MIL-S-8802, Type I dichromate cure and for the one MIL-S-83430 manganese dioxide cure, whose

TABLE 8

FUEL TANK SEALANTS

Conditioning	MIL-S-8802E, Type I Dichromate Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell	MIL-S-8802E, Type II Manganese Dioxide Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell
Controls	23	(40.3)	100		33	(57.8)	100	
7 days at 140°F(60°C) in Pet. JP-4	20	(35.0)	100	0.8	32	(56.0)	100	2.2
7 days at 140°F(60°C) in Shale JP-4	19	(33.3)	100	-0.3	30	(52.5)	100	0.7
7 days at 140°F(60°C) in Pet. JP-4[1]	17	(29.8)	100	18	13/ 24	(22.7/ 42.0)	100	7.5
7 days at 140°F(60°C) in Shale JP-4[1]	20	(35.0)	100	4.2	35	(61.3)	100	5.9
6 months at 140°F(60°C) in Pet. JP-4	16	(28.0)	100	-3.9	12	(21.0)	100	8.6
6 months at 140°F(60°C) in Shale JP-4	13	(22.8)	100	-4.3	11	(19.3)	100	4.6

[1]25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 8 (Concluded)

FUEL TANK SEALANTS

Conditioning	MIL-S-8802E, Type I Dichromate Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell	MIL-S-8802E, Type II Manganese Dioxide Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell
14 days at 140°F(60°C) in Pet. JP-4 +				1.3				3.8
7 days at 140°F(60°C) in Shale JP-4	22	(38.5)	100	1.1	26	(4[illegible].5)	100	1.7
14 days at 77°F(25°C) in Pet. JP-4 +				2.4				2.4
7 days at 77°F(25°C) in Shale JP-4	20	(35.0)	100	1.0	34	(59.5)	100	0.9
14 days at 140°F(60°C) in Pet. JP-8 +				1.3				1.1
7 days at 140°F(60°C) in Shale JP-4	19	(33.3)	100	0.3	22	(38.5)	100	2.6
14 days at 77°F(25°C) in Pet. JP-8 +				1.6				1.7
7 days at 77°F(25°C) in Shale JP-4	17	(29.8)	100	1.4	40	(70.0)	100	2.0

TABLE 9

FUEL TANK SEALANTS
CURING TYPE

Conditioning	MIL-S-83430 Manganese Dioxide Cure				MIL-S-83430 Manganese Dioxide Cure			
	Peel Load		% Cohesive Failure	% Vol. Swell	Peel Load		% Cohesive Failure	% Vol. Swell
	lbs/in	(N/cm)			lbs/in	(N/cm)		
Controls	40	(70.0)	100		18	(31.5)	100	
7 days at 140°F(60°C) in Pet. JP-4	33	(57.8)	100	0	16	(28.0)	100	2.6
7 days at 140°F(60°C) in Shale JP-4	37	(64.8)	100	-1.3	18	(31.5)	100	0.7
7 days at 140°F(60°C) in Pet. JP-4[1]	28	(49.0)	100	3.5	24	(42.0)	100	5.0
7 days at 140°F(60°C) in Shale JP-4[1]	34	(59.5)	100	2.9	28	(49.0)	100	6.4
6 months at 140°F(60°C) in Pet. JP-4	28	(49.0)	100	-4.0	9	(15.8)	100	8.6
6 months at 140°F(60°C) in Shale JP-4	29	(50.8)	100	-4.8	8	(14.0)	100	4.5

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 9 (Concluded)

FUEL TANK SEALANTS
CURING TYPE

Conditioning	MIL-S-83430 Manganese Dioxide Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell	MIL-S-83430 Manganese Dioxide Cure Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell
14 days at 140°F(60°C) in Pet. JP-4 +				-0.8				5.7
7 days at 140°F(60°C) in Shale JP-4	31	(54.3)	100	-1.5	28	(49.0)	100	2.2
14 days at 77°F(25°C) in Pet. JP-4 +				1.1				2.9
7 days at 77°F(25°C) in Shale JP-4	27	(42.3)	100	0.6	30	(52.5)	100	0.9
14 days at 140°F(60°C) in Pet. JP-8 +				-1.8				1.1
7 days at 140°F(60°C) in Shale JP-4	33	(57.8)	100	-1.6	14	(24.5)	100	2.6
14 days at 77°F(25°C) in Pet. JP-8 +				0.3				1.7
7 days at 77°F(25°C) in Shale JP-4	41	(71.8)	100	1.6	18	(31.5)	100	2.0

TABLE 10

FUEL TANK SEALANTS
CURING TYPE

Conditioning	MIL-S-7502 Lead Dioxide Cure: Peel Load				Q94-002 Fluorosilicone: Peel Load			
	lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell	lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell
Controls	41	(71.8)	100		7	(12.3)	100	
7 days at 140°F(60°C) in Pet. JP-4	46	(80.5)	95	-5.2	4	(7.0)	100	9.1
7 days at 140°F(60°C) in Shale JP-4	55	(96.3)	100	-4.5	4	(7.0)	100	6.4
7 days at 140°F(60°C) in Pet. JP-4[1]	48	(84.0)	100	-21.1	5	(8.8)	100	7.8
7 days at 140°F(60°C) in Shale JP-4[1]	58	(101.6)	100	-7.8	5	(8.8)	100	9.0
6 months at 140°F(60°C) in Pet. JP-4	37	(64.8)	100	-17.0	4	(7.0)	---[2]	9.1
6 months at 140°F(60°C) in Shale JP-4	36	(63.0)	100	-17.6	4	(7.0)	---[2]	6.4

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

[2] Stained panel

TABLE 10 (Concluded)

FUEL TANK SEALANTS
CURING TYPE

Conditioning	MIL-S-7502 Lead Dioxide Cure: Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell	Q94-002 Fluorosilicone: Peel Load lbs/in	(N/cm)	% Cohesive Failure	% Vol. Swell
14 days at 140°F(60°C) in Pet. JP-4 +				-6.6				8.5
7 days at 140°F(60°C) in Shale JP-4	51	(89.3)	100	-9.4	4	(7.0)	100	6.4
14 days at 77°F(25°C) in Pet. JP-4 +				1.5				7.3
7 days at 77°F(25°C) in Shale JP-4	55	(96.3)	100	-1.1	4	(7.0)	100	5.1
14 days at 140°F(60°C) in Pet. JP-8 +				-5.7				3.7
7 days at 140°F(60°C) in Shale JP-4	49	(85.8)	100	-6.6	5	(8.8)	100	6.2
14 days at 77°F(25°C) in Pet. JP-8 +				-0.1				3.5
7 days at 77°F(25°C) in Shale JP-4	59	(103.3)	100	-0.3	5	(8.8)	100	6.3

peel strength was unaffected, were very low to negative in value, except in those fuels with 25 percent aromatics. MIL-S-8802 Type II, and the second MIL-S-83430, both manganese dioxide cure sealants, had smaller volume changes after exposure to shale oil JP-4 than after exposure to petroleum JP-4. Volume changes of MIL-S-7502 lead dioxide cure were negative after exposure to both types of fuel.

Values of peel strength and volume change for Q94-002 fluorosilicone sealant were unaffected by fuel agings.

Fuel Tank Sealants - Non-curing Type

Non-curing groove injection sealants are used to seal wet fuel tanks. Three sealants were utilized:

PR 703 Polysulfide
94-031 Fluorosilicone
G651 Cyanosilicone

The sealants were evaluated for pressure rupture and for percent volume swell after conditioning in the petroleum and shale oil produced fuels. The same material aging schedule used for the curing type sealants was followed. Results are shown in Table 11.

Pressure rupture values tripled for PR 703 polysulfide after aging for six months in both types of fuel. PR 703 also showed an increase in pressure rupture after aging for seven days in high aromatic shale oil JP-4. Pressure rupture values for 94-031 fluorosilicone were not greatly affected by aging in either fuel, although a decrease in pressure did occur for the high aromatic fuels. A slight increase in pressure rupture for G651 occurred after aging in the petroleum and shale oil fuels. The rupture pressures for G651 were lowest after aging at room temperature.

The percent volume swell of PR 703 remained fairly constant in all fuels with the exception of high aromatic petroleum JP-4, in which the swell increased. Volume swell values for 94-031

TABLE 11

FUEL TANK SEALANTS
NON-CURING TYPE

Conditioning	PR 733 Polysulfide: Pressure Rupture, Inches Hg	PR 733 Polysulfide: Pressure Rupture, (mm Hg)	PR 733 Polysulfide: % Vol. Swell	94-031 Fluorosilicone: Pressure Rupture, Inches Hg	94-031 Fluorosilicone: Pressure Rupture, (mm Hg)	94-031 Fluorosilicone: % Vol. Swell	G651 Cyanosilicone: Pressure Rupture, Inches Hg	G651 Cyanosilicone: Pressure Rupture, (mm Hg)	G651 Cyanosilicone: % Vol. Swell
Controls	18.4	(467)	---	32.1	(815)	---	19.0	(483)	---
7 days at 140°F(60°C) in Pet. JP-4	20.2	(513)	4.5	24.5	(622)	9.8	16.7	(424)	14.6
7 days at 140°F(60°C) in Shale JP-4	19.8	(503)	3.0	22.4	(569)	6.3	17.9	(455)	11.5
7 days at 140°F(60°C) in Pet. JP-4[1]	15.1	(384)	12.1	17.3	(432)	17.4	15.1	(335)	14.7
7 days at 140°F(60°C) in Shale JP-4[1]	40.0	(1016)	6.5	15.8	(401)	11.7	10.4	(264)	12.1
6 months at 140°F(60°C) in Pet. JP-4	60.0	(1524)	5.7	23.3	(592)	11.7	23.4	(594)	10.0
6 months at 140°F(60°C) in Shale JP-4	60.0+	(1524+)	4.6	33.8	(859)	7.8	30.0	(762)	8.8

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 11 (Concluded)

FUEL TANK SEALANTS
NON-CURING TYPE

Conditioning	PR 703 Polysulfide: Pressure Rupture Inches Hg	PR 703 Polysulfide: Pressure Rupture (mm Hg)	PR 703 Polysulfide: % Vol. Swell	94-031 Fluorosilicone: Pressure Rupture Inches Hg	94-031 Fluorosilicone: Pressure Rupture (mm Hg)	94-031 Fluorosilicone: % Vol. Swell	G651 Cyanosilicone: Pressure Rupture Inches Hg	G651 Cyanosilicone: Pressure Rupture (mm Hg)	G651 Cyanosilicone: % Vol. Swell
14 days at 140°F(60°C) in Pet. JP-4 +			4.6			11.7			11.3
7 days at 140°F(60°C) in Shale JP-4	24.4	(620)	3.0	21.7	(551)	9.2	17.1	(434)	11.6
14 days at 77°F(25°C) in Pet. JP-4 +			2.7			4.5			13.6
7 days at 77°F(25°C) in Shale JP-4	19.0	(483)	1.5	30.2	(767)	2.0	9.5	(241)	11.7
14 days at 140°F(60°C) in JP-8 +			2.6			4.7			5.4
7 days at 140°F(60°C) in Shale JP-4	23.4	(594)	2.6	29.0	(737)	6.5	14.5	(368)	8.1
14 days at 77°F(25°C) in JP-8 +			1.0			0.6			2.3
7 days at 77°F(25°C) in Shale JP-4	14.6	(371)	-0.9	11.2	(284)	3.9	9.9	(251)	4.9

sealant were smaller in shale oil JP-4 than in petroleum JP-4. 94-031 was most affected after exposure to petroleum JP-8. G651 cyanosilicone sealant showed basically the same volume swell reactions as the fluorosilicone to the various fuels.

Bladder Materials

Four fuel cell bladder materials were included in the fuel compatibility program. They were:

Goodyear Pliocel Nylon
Goodyear 51956 Buna-N
Goodyear 80C29 Urethane
Goodyear 82C39 New Urethane

Materials evaluations included tensile strength, percent elongation, and percent volume swell. Peel strength determinations were included for the Pliocel and buna-N materials as well as for one bladder repair adhesive, Goodyear FT-134 Buna-N.

The materials were subjected to the following conditions:

A. None (Original properties)

B. 7 days at 140°F (60°C) in Petroleum JP-4

C. 7 days at 140°F (60°C) in Shale Oil JP-4

D. 6 months at 140°F (60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F (60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F (60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F (60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.5 weight percent

H. After aging 14 days at 140°F (60°C) in Petroleum JP-4 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F (60°C) in Petroleum JP-8 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (Also, measure volume change when removed from JP-8).

Permeability measurements were also made on the four bladder materials and on two additional bladder constructions, BTC-86 and FT-99 buna-N innerliner. The materials were subjected to the following agings:

A. 7 days at 77°F (25°C) in Petroleum JP-4

B. 7 days at 77°F (25°C) in Shale Oil JP-4

The results of the bladder materials tests are shown in Tables 12, 13, and 14. As indicated in Table 12, the 51956 buna-N material had a loss of tensile strength and percent elongation after six months aging in shale oil JP-4, a reaction similar to the reactions of buna-N O-rings in shale oil JP-4. The poor performance of the 51956 was subsequently explained by the retest of the buna-N O-ring material in shale oil produced fuels from more than one source of supply.

Table 12 also shows that 80C29 urethane underwent a loss of tensile strength and percent elongation after long-time exposure to shale oil JP-4, while the second urethane, 82C39, was unaffected. The sample of 80C29 used in this program was approximately three years old. A new sample of 80C29 was obtained from Goodyear and a retest, using the same aging schedule as that used for buna-N O-rings, was initiated:

A. None (original properties)

B. 30, 60, 90, 120, 150, 180, 270, and 360 days at 140°F (60°C) in each of the four fuel samples (Shale oil JP-4 from GE Evendale and from Pratt & Whitney; Petroleum JP-4; and Petroleum JP-4 with 5 ppm benzotriazole).

The results of the retest, shown in Tables 15 and 16, indicated no loss of properties for the new sample of 80C29 in any of the test fluids.

TABLE 12

BLADDER MATERIALS

Tensile Strength and Percent Elongation

Conditioning	Pliocel Tensile Strength psi (MPa)	Pliocel % Elongation	Buna-N 51956 Tensile Strength psi (MPa)	Buna-N 51956 % Elongation	Urethane 80C29 Tensile Strength psi (MPa)	Urethane 80C29 % Elongation	New Urethane 82C39 Tensile Strength psi (MPa)	New Urethane 82C39 % Elongation
Control	11590(79.9)	29	2130(14.7)	420	4510(31.1)	290	3040(21.0)	200
7 days at 140°F(60°C) in Pet. JP-4	12070(83.2)	27	2040(14.1)	400	4130(28.5)	350	2540(17.5)	210
7 days at 140°F(60°C) in Shale JP-4	12000(82.7)	24	2200(15.2)	400	3810(26.3)	340	2600(17.9)	200
7 days at 140°F(60°C) in Pet. JP-4[1]	11780(81.2)	20	1760(12.1)	390	3640(25.1)	390	2600(17.9)	210
7 days at 140°F(60°C) in Shale JP-4[1]	12320(84.9)	26	1760(12.1)	390	2840(19.6)	330	2230(15.4)	260
14 days at 140°F(60°C) in Pet. JP-4 + 7 days at 140°F(60°C) in Shale JP-4	12230(84.3)	19	2300(15.9)	390	4210(29.0)	350	2340(16.1)	220
14 days at 140°F(60°C) in Pet. JP-8 + 7 days at 140°F(60°C) in Shale JP-4	11930(82.2)	22	2220(15.3)	390	4040(27.9)	350	2440(16.8)	210
6 months at 140°F(60°C) in Pet. JP-4	12340(85.1)	26	2000(13.8)	200	2730(18.8)	350	2210(15.2)	210
6 months at 140°F(60°C) in Shale JP-4	12840(88.5)	22	840(5.8)	90	830(5.7)	140	2540(17.5)	210

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 13

BLADDER MATERIALS
Percent Volume Swell

Conditioning	Pliocel % Volume Swell	51556 % Volume Swell	80C29 % Volume Swell	82C39 % Volume Swell	Pliocel T Peel Load lbs/in(N/cm)	51556 T Peel Load lbs/in(N/cm)	FT-134 T Peel Load lbs/in(N/cm)
Control	---	---	---	---	14.1(24.7)	74.4(130.2)	38.4(67.2)
7 days at 140°F(60°C) in Pet. JP-4	1.2	0.5	9.6	17.6	15.4(26.9)	46.2(80.9)	34.4(60.2)
7 days at 140°F(60°C) in Shale JP-4	-0.4	-4.4	7.2	15.1	13.6(23.8)	67.8(118.7)	38.9(68.1)
7 days at 140°F(60°C) in Pet. JP-4[1]	5.8	5.1	19.0	20.2	13.3(23.3)	41.9(73.4)	14.4(25.2)
7 days at 140°F(60°C) in Shale JP-4[1]	1.4	4.3	13.2	28.6	14.9(26.1)	46.8(81.9)	24.6(43.1)
14 days at 140°F(60°C) in Pet. JP-4 +	2.2	-1.5	10.2	21.4			
7 days at 140°F(60°C) in Shale JP-4	1.4	-3.5	8.0	19.7	11.9(20.8)	51.3(89.8)	16.2(28.4)
14 days at 140°F(60°C) in Pet. JP-8 +	3.2	-3.6	10.4	12.0			
7 days at 140°F(60°C) in Shale JP-4	0.8	-4.3	8.7	17.9	15.8(27.6)	68.4(119.8)	11.3(19.8)
6 months at 140°F (60°C) in Pet. JP-4	0.3	-2.7	11.0	20.1	15.2(26.6)	63.6(111.5)	5.9(10.3)
6 months at 140°F (60°C) in Shale JP-4	1.2	-5.3	9.6	19.7	12.1(21.2)	59.8(104.7)	7.2(12.6)

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

TABLE 14

BLADDER MATERIALS
Permeability

Conditioning	BTC-86 Permeability oz/ft^2/24 hr	FT-99 Permeability oz/ft^2/24 hr	Plioc[illegible]l Permeability oz/ft^2/24 hr	82C3[illegible] Permeability oz/ft^2/24hr	8[illegible]C29 Permeability oz/ft^2/24 hr	[illegible]1956 Permeability oz/ft^2/24 hr
8 days at 77°F (25°C) in Pet. JP-4	[illegible].03[illegible]	[illegible].0016	[illegible].[illegible]33	.[illegible]	0	[illegible].[illegible]
8 days at 77°F (25°C) in Shale JP-4	0.[illegible]24	0.010	0.024	[illegible].[illegible]4	0	[illegible].[illegible]02

TABLE 15

BLADDER MATERIAL
80C29 URETHANE

Tensile Strength

	Days Aging at 140°F (60°C)								
	Original psi (MPa)	30 psi (MPa)	60 psi (MPa)	90 psi (MPa)	120 psi (MPa)	150 psi (MPa)	180 psi (MPa)	270 psi (MPa)	360 psi (MPa)
Shale oil produced JP-4 from GE Evendale	5490 (37.9)	5470 (37.7)	5910 (40.7)	5840 (40.3)	5670 (39.1)	5430 (37.4)	6130 (42.3)	5920 (40.8)	6260 (43.2)
Shale oil produced JP-4 from Pratt & Whitney	5490 (37.9)	4880 (33.6)	5860 (40.4)	5910 (40.7)	5620 (38.7)	6070 (41.9)	5700 (39.3)	5810 (40.1)	5940 (40.9)
Petroleum produced JP-4	5490 (37.9)	4320 (29.8)	5350 (36.9)	5760 (39.7)	5250 (34.9)	5390 (37.1)	5440 (37.5)	5770 (39.8)	5920 (40.8)
Petroleum produced JP-4 w/5 ppm benzotriazole	5490 (37.9)	4710 (32.5)	5160 (32.5)	4950 (34.1)	5200 (37.3)	5290 (36.5)	5560 (38.3)	5970 (41.2)	5410 (37.3)

TABLE 16

BLADDER MATERIAL
80C29 URETHANE

Percent Elongation

	Days at 140°F (60°C)								
	Original	30	60	90	120	150	180	270	360
Shale oil produced JP-4 from GE Evendale	350	330	330	325	340	330	350	315	340
Shale oil produced JP-4 from Pratt & Whitney	350	350	320	320	330	325	320	310	310
Petroleum produced JP-4	350	330	360	355	360	360	350	345	380
Petroleum produced JP-4 w/5 ppm benzotriazole	350	370	340	335	350	325	360	380	370

The volume swell data in Table 13 show that all the materials had slightly lower values in shale oil JP-4 than in petroleum JP-4, as did the elastomeric O-ring materials. Peel strengths of the Pliocel and 51956 bladder constructions were not greatly affected by aging in either fuel. FT-134 buna-N repair adhesive was affected by long-term aging in both petroleum and shale oil produced fuels.

Self-Sealing Bladder Material

Volume swell determinations were also made for one self-sealing material, Goodyear 26950. Samples of the material were aged in petroleum produced JP-4 and in shale oil produced JP-4 for seven days at 77°F (24°C). The indicated volume change after aging in petroleum JP-4 was greater than the volume change in shale oil JP-4. Both materials, however, exhibited very large volume changes in excess of 1,000 percent as shown in Table 17.

Fire Suppressant Foams

Two fuel cell fire suppressant foams were also evaluated in petroleum and shale oil derived JP-4 fuels. One foam was a red polyester polyurethane (MIL-B-83054B, Type III); and, the second foam was a blue polyether polyurethane (MIL-B-83054B, Type V). All foam specimens were supplied as precut tensile strength dogbones from Scott Foam. As shown in Table 18, red foam was virtually unaffected by aging in either fuel; blue foam, however, exhibited an approximate 50 percent reduction in tensile strength after aging in both fuels for six months at 140°F (60°C).

Structural Adhesives

Structural adhesive materials that are in use on current aircraft systems were included in the materials evaluation. These materials included:

TABLE 17

SELF-SEALING MATERIAL
26950

Conditioning	% Volume Swell
7 days @ 77°F (25°C) in Pet. JP-4	1600
7 days @ 77°F (25°C) in Shale Oil JP-4	1350

TABLE 18

FIRE SUPPRESSANT FOAMS

Conditioning	MIL-B-83054B Type III Tensile Strength psi	(MPa)	% Elongation	% Volume Swell	MIL-B-83054B Type V Tensile Strength psi	(MPa)	% Elongation	% Volume Swell
Control	30	(0.21)	310		17	(0.12)	120	
7 Days at 140°F (60°C) in Pet. JP-4	29	(0.20)	340	2.9	10	(0.07)	100	5.8
7 Days at 140°F (60°C) in Shale JP-4	30	(0.21)	350	4.7	19	(0.13)	90	8.3
7 Days at 140°F (60°C) in Pet. JP-4[1]	27	(0.18)	330	N/A	14	(0.09)	170	N/A
7 Days at 140°F (60°C) in Shale JP-4[1]	28	(0.19)	340	N/A	16	(0.11)	160	N/A
14 Days at 140°F (60°C) in Pet. JP-4 + 7 Days at 140°F (60°C) in Shale JP-4	30	(0.21)	350	1.9 7.4	15	(0.10)	140	7.9 7.8
14 Days at 140°F (60°C) in Pet. JP-8 + 7 Days at 140°F (60°C) in Shale JP-4	29	(0.20)	360	7.3	14	(0.09)	140	11.0
6 Months at 140°F (60°C) in Pet. JP-4	29	(0.20)	360	Lost Data	9	(0.06)	120	No data available
6 Months at 140°F (60°C) in Shale JP-4	29	(0.20)	340	-1.8	9	(0.11)	75	No data available

[1] 25% Aromatic Content; 0.4% Sulfur; 0.005% Mercaptan

A. XA-3517 epoxy polyamide

B. FM-47 with FM-47 liquid primer vinyl phenolic

C. AF-143-2 with EC 3917 primer modified high temperature epoxy

D. AF-126-2 with EC 2320 primer nitrile modified epoxy

E. Epon 828/dimethyltriamine unmodified epoxy

F. FM-73 with BR-127 primer nitrile modified epoxy

G. AF-10 with EC 1290 primer Scotchweld

H. AF-10 with EC 3950 primer Scotchweld

Double lap shear specimens of each adhesive type were prepared for the following agings:

A. None (original properties)

B. 7 days at 140°F (60°C) in Petroleum JP-4

C. 7 days at 140°F (60°C) in Shale Oil JP-4

D. 6 months at 140°F (60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F (60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F (60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F (60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

H. After aging 14 days at 140°F (60°C) in Petroleum JP-4 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F (60°C) in Petroleum JP-8 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from JP-8).

The substrate materials for the lap shear specimens were 2024-T3 aluminum panels. All panels were solvent wiped, washed with a non-chlorinated cleaner, degreased, then acid etched for ten minutes at 140°F (60°C). Double lap shear test results are summarized in Tables 19 and 20.

Shear strengths of all the adhesives tested, with the exception of the epoxy polyamide, were virtually unaffected by aging in either petroleum or shale oil produced fuels. Shear strengths of the epoxy polyamide were reduced by more than 50 percent in both fuels after long term exposure and after short term exposure to high aromatics.

Fuel Tank Coatings

Three integral fuel tank corrosion prevention coatings were also evaluated. The coatings included:

A. MIL-S-4383 Buna-N

B. MIL-C-27725 Polyurethane

C. BMS 10-20 Epoxy

Pencil hardness of each of the three materials was determined after the following agings:

A. None (Original properties)

B. 7 days at 140°F (60°C) in Petroleum JP-4

C. 7 days at 140°F (60°C) in Shale Oil JP-4

D. 6 months at 140°F (60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F (60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F (60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F (60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

TABLE 19

STRUCTURAL ADHESIVES

Conditioning	XA-3517 Shear Strength psi (MPa)	XA-3517 % Coh. Failure Mode	FM-47 FM-47 Primer Shear Strength psi (MPa)	FM-47 FM-47 Primer % Coh. Failure Mode	AF-143-2 EC-3917 Primer Shear Strength psi (MPa)	AF-143-2 EC-3917 Primer % Coh. Failure Mode	AF-126-2 EC-2320 Primer Shear Strength psi (MPa)	AF-126-2 EC-2320 Primer % Coh. Failure Mode
Controls	2960(20.4)	85	3980(27.4)[2]		3290(22.7)	95	4180(28.8)	95
7 Days at 140°F(60°C) in Pet. JP-4	2200(15.2)	85	3900(26.9)	20	3290(22.7)	95	4160(28.7)	90
7 Days at 140°F(60°C) in Shale JP-4	2900(20.0)	95	3940(27.2)	40	3270(22.5)	95	4150(28.6)	95
7 Days at 140°F(60°C) in Pet. JP-4[1]	1270(8.8)	70	3910(27.0)	40	3270(22.5)	100	4140(28.5)	95
7 Days at 140°F(60°C) in Shale JP-4[1]	1470(10.1)	50	3860(26.6)	45	3250(22.4)	95	4170(28.7)	95
14 Days at 140°F(60°C) in Pet. JP-4 + 7 Days at 140°F(60°C) in Shale JP-4	2190(15.1)	85	3920(27.0)	40	3310(22.8)	100	4130(28.5)	95
14 Days at 140°F(60°C) in Pet. JP-8 + 7 Days at 140°F(60°C) in Shale JP-4	2850(19.6)	95	3940(27.2)	70	3310(22.8)	100	4170(28.7)	100
6 Months at 140°F(60°C) in Pet. JP-4	1120(7.7)	65	3970(27.4)	45	3510(24.1)	100	4170(28.7)	95
6 Months at 140°F(60PC) in Shale JP-4	1370(9.4)	70	3880(26.7)	55	3300(22.8)	95	4080(28.1)	95

[1]25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan
[2]Metal failure

TABLE 20

STRUCTURAL ADHESIVES

Conditioning	Epon 828/DTA		FM 73 BR-127 Primer		AF-10 EC-1290 Primer		AF-10 EC-3950 Primer	
	Shear Strength psi (MPa)	% Coh. Failure Mode	Shear Strength psi (MPa)	% Coh. Failure Mode	Shear Strength psi (MPa)	% Coh. Failure Mode	Shear Strength psi (MPa)	% Coh. Failure Mode
Controls	990(6.9)	60	4090(28.2)[2]		3480(24.0)	75	3300(22.7)	90
7 Days at 140°F(60°C) in Pet. JP-4	1520(10.5)	75	4120(28.4)[2]		3470(23.9)	50	3620(25.0)	75
7 Days at 140°F(60°C) in Shale JP-4	1790(12.3)	45	4090(28.2)[2]		3410(23.5)	65	3450(23.8)	95
7 Days at 140°F(60°C) in Pet. JP-4[1]	1010(7.0)	70	4100(28.3)[2]		3490(24.1)	65	3390(23.4)	100
7 Days at 140°F(60°C) in Shale JP-4[1]	890(6.1)	50	4100(28.3)[2]		3650(25.2)	70	3620(24.9)	95
14 Days at 140°F(60°C) in Pet. JP-4++ 7 Days at 140°F(60°C) in Shale JP-4	1340(9.2)	55	4090(28.2)[2]		3720(25.7)	75	3620(24.9)	100
14 Days at 140°F(60°C) in Pet. JP-8 + 7 Days at 140°F(60°C) in Shale JP-4	1210(8.3)	50	4120(28.4)[2]		3680(25.4)	80	3690(25.4)	100
6 Months at 140°F(60°C) in Pet. JP-4	740(5.1)	50	4170(28.8)[2]		3650(25.2)	70	3930(27.1)	95
6 Months at 140°F(60°C) in Shale JP-4	1510(10.4)	60	4080(28.1)[2]		3810(26.3)	70	3770(26.0)	95

[1]25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan
[2]Metal failure

H. After aging 14 days at 140°F (60°C) in Petroleum JP-4 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F (60°C) in Petroleum JP-8 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from JP-8)

Values obtained for each of the materials are presented in Table 21. Some variation in hardness occurred for the buna-N material, which appeared softer after exposure to high aromatics. The other materials, both harder than 9H pencil lead, were not affected by exposure to any of the fuels.

Wire Insulation Materials

Three electrically insulating sheet materials were also selected for evaluation. The materials included Teflon (TFE), Nylon 101, and polyethylene. Standard Die "C" dogbone test specimens were prepared for the determination of tensile strength and percent elongation as a function of conditioning. The following fuel agings were used:

A. None (original properties)

B. 7 days at 140°F (60°C) in Petroleum JP-4

C. 7 days at 140°F (60°C) in Shale Oil JP-4

D. 6 months at 140°F (60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F (60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F (60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F (60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

TABLE 21

FUEL TANK COATINGS

PENCIL HARDNESS

Conditioning	MIL-S-4383	BMS 10-20	MIL-C-27725
Controls	HB	$9H^+$	$9H^+$
7 Days at 140°F (60°C) in Pet. JP-4	2B	$9H^+$	$9H^+$
7 Days at 140°F (60°C) in Shale JP-4	B	$9H^+$	$9H^+$
7 Days at 140°F (60°C) in Pet. JP-4[1]	3B	$9H^+$	$9H^+$
7 Days at 140°F (60°C) in Shale JP-4[1]	B	$9H^+$	$9H^+$
14 Days at 140°F (60°C) in Pet. JP-4 + 7 Days at 140°F (60°C) in Shale JP-4	HB	$9H^+$	$9H^+$
14 Days at 140°F (60°C) in JP-8 + 7 Days at 140°F (60°C) in Shale JP-4	B	$9H^+$	$9H^+$
6 Months at 140°F (60°C) in Pet. JP-4	HB	$9H^+$	$9H^+$
6 Months at 140°F (60°C) in Shale JP-4	H	$9H^+$	$9H^+$

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

H. After aging 14 days at 140°F (60°C) in Petroleum JP-4 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F (60°C) in Petroleum JP-8 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from JP-8).

Test results for all three materials are presented in Table 22. Teflon (TFE) was unaffected by fuel conditioning. Nylon 101 had higher elongations in shale produced JP-4 than in petroleum JP-4. The elongation of Nylon 101, however, was substantially reduced after exposure to both petroleum and shale oil produced fuels after the six month aging. The tensile strength of polyethylene was reduced approximately 25 percent after exposure to all fuels. Percent elongation was substantially higher in all cases.

Self-Sealing Hose

AR 184 red self-sealing hose, an inner tube material from B.F. Goodrich was also included in the materials evaluation. Tensile strength, elongation, hardness, and volume change properties were determined after the following agings:

A. None (original properties)

B. 7 days at 140°F (60°C) in Petroleum JP-4

C. 7 days at 140°F (60°C) in Shale Oil JP-4

D. 6 months at 140°F (60°C) in Petroleum JP-4, changing fuel every 30 days

E. 6 months at 140°F (60°C) in Shale Oil JP-4, changing fuel every 30 days

F. 7 days at 140°F (60°C) in Petroleum JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

G. 7 days at 140°F (60°C) in Shale Oil JP-4 with the aromatic content at 25%, mercaptan sulfur at 0.005 weight percent, and total sulfur at 0.4 weight percent

TABLE 22

WIRE INSULATION MATERIALS

Conditioning	Teflon (TFE) Tensile Strength psi	Teflon (TFE) Tensile Strength (MPa)	Teflon (TFE) % Elong.	Nylon 101 Tensile Strength psi	Nylon 101 Tensile Strength (MPa)	Nylon 101 % Elong.	Polyethylene Tensile Strength psi	Polyethylene Tensile Strength (MPa)	Polyethylene % Elong.
Control	2000	(13.8)	80	10400	(72.0)	60	4900	(34.1)	15
7 days at 140°F (60°C) in Pet. JP-4	2300	(15.5)	80	7700	(53.2)	160	3700	(25.8)	460
7 days at 140°F (60°C) in Shale JP-4	1800	(12.2)	70	9600	(66.2)	330	3600	(25.1)	460
7 days at 140°F (60°C) in Pet. JP-4[1]	2000	(13.8)	80	10400	(71.9)	180	3600	(25.1)	620
7 days at 140°F (60°C) in Shale JP-4[1]	1700	(12.0)	90	8900	(61.3)	320	3700	(25.8)	490
14 days at 140°F (60°C) in Pet. JP-4 + 7 days at 140°F (60°C) in Shale JP-4	1900	(13.4)	80	9200	(63.6)	95	3700	(25.8)	490
14 days at 140°F (60°C) in Pet. JP-8 + 7 days at 140°F (60°C) in Shale JP-4	2000	(13.7)	70	9600	(66.1)	120	3400	(23.9)	490
6 months at 140°F (60°C) in Pet. JP-4	1700	(12.0)	60	12100	(83.3)	9	3900	(27.2)	500
6 months at 140°F (60°C) in Shale JP-4	1800	(12.3)	80	9900	(68.0)	10	3300	(22.8)	670

[1] 25% Aromatic Content; 0.4% Sulfur; 0.005% Mercaptan

H. After aging 14 days at 140°F (60°C) in Petroleum JP-4 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from Petroleum JP-4)

I. After aging 14 days at 140°F (60°C) in Petroleum JP-8 followed by 7 days at 140°F (60°C) in Shale Oil JP-4 (also, measure volume change when removed from JP-8).

The results in Table 23 indicate that the properties of the self-sealing hose material are similar in both petroleum and shale oil fuels.

TABLE 23

SELF-SEALING HOSE

Conditioning	Tensile Strength psi (MPa)	Elongation (%)	Hardness Shore A	Volume Change, %
Control	2105 (14.5)	440	64	
7 days at 140°F (60°C) in Pet. JP-4	1640 (11.3)	320	55	20.9
7 days at 140°F (60°C) in Shale JP-4	1730 (11.9)	350	56	19.3
7 days at 140°F (60°C) in Pet. JP-4[1]	1320 (9.1)	295	49	31.9
7 days at 140°F (60°C) in Shale JP-4[1]	1300 (9.0)	280	54	32.3
14 days at 140°F (60°C) in Pet. JP-4 +	1750 (12.1)	340	---	20.5
7 days at 140°F (60°C) in Shale JP-4				18.5
14 days at 140°F (60°C) in Pet. JP-8 +	1800 (12.4)	350	57	19.8
7 days at 140°F (60°C) in Shale JP-4				18.6
6 months at 140°F (60°C) in Pet. JP-4	1360 (9.4)	270	57	21.5
6 months at 140°F (60°C) in Shale JP-4	1550 (10.7)	260	61	19.4

[1] 25% Aromatic content; 0.4% Sulfur; 0.005% Mercaptan

III. CONCLUSIONS

The long term evaluation of the effects of shale oil produced JP-4 on aircraft construction materials showed:

1. There is no significant difference in the compatibility of either shale oil JP-4 or petroleum JP-4 for most materials.

2. The only materials affected by shale oil JP-4 were buna-N and polyurethane.

3. Repeat tests using the same supply of shale oil JP-4 showed deterioration of buna-N; no deterioration occurred on newer samples of polyurethane.

4. Tests using a second supply of shale oil JP-4 showed no deterioration of either buna-N or polyurethane.

5. There is some evidence that the presence of benzotriazole in the fuel may have affected buna-N.

6. Most seal and sealant materials showed slightly less volume swell in shale oil JP-4 than in petroleum JP-4. This may cause leakage when changing from one fuel to the other.

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